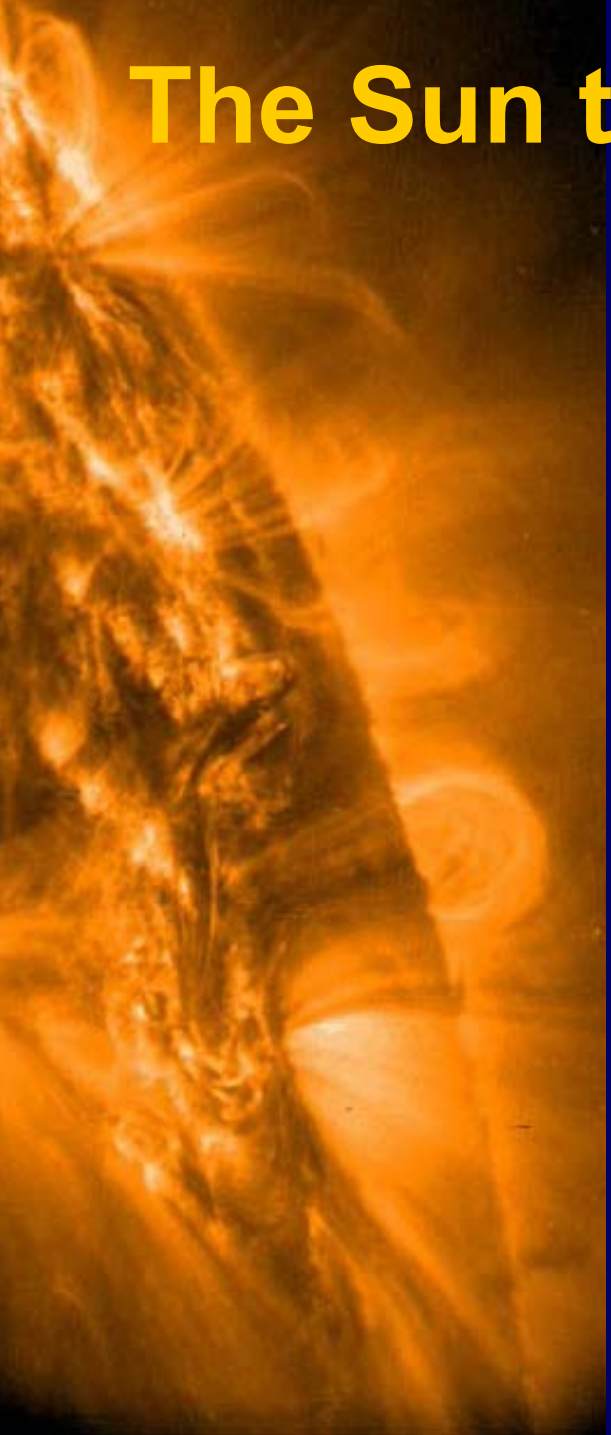
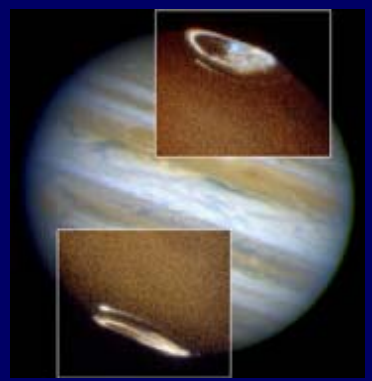


The Sun to the Earth – and Beyond

An Integrated Strategy for Solar and Space Physics, 2003-2013

Report of the
Solar and Space Physics Survey Committee
National Research Council

In press, 2003
National Academies Press, Washington



Louis J. Lanzerotti
Chair, SSP Survey Committee

Space Weather Week
Boulder, Colorado, 19May 2003

The Charge to the Survey Committee:

- Conduct a **BROADLY BASED ASSESSMENT** of the scientific priorities of U.S. solar and space physics research programs. Consider contributions from all agencies (**NASA, NSF, NOAA, DoD**)

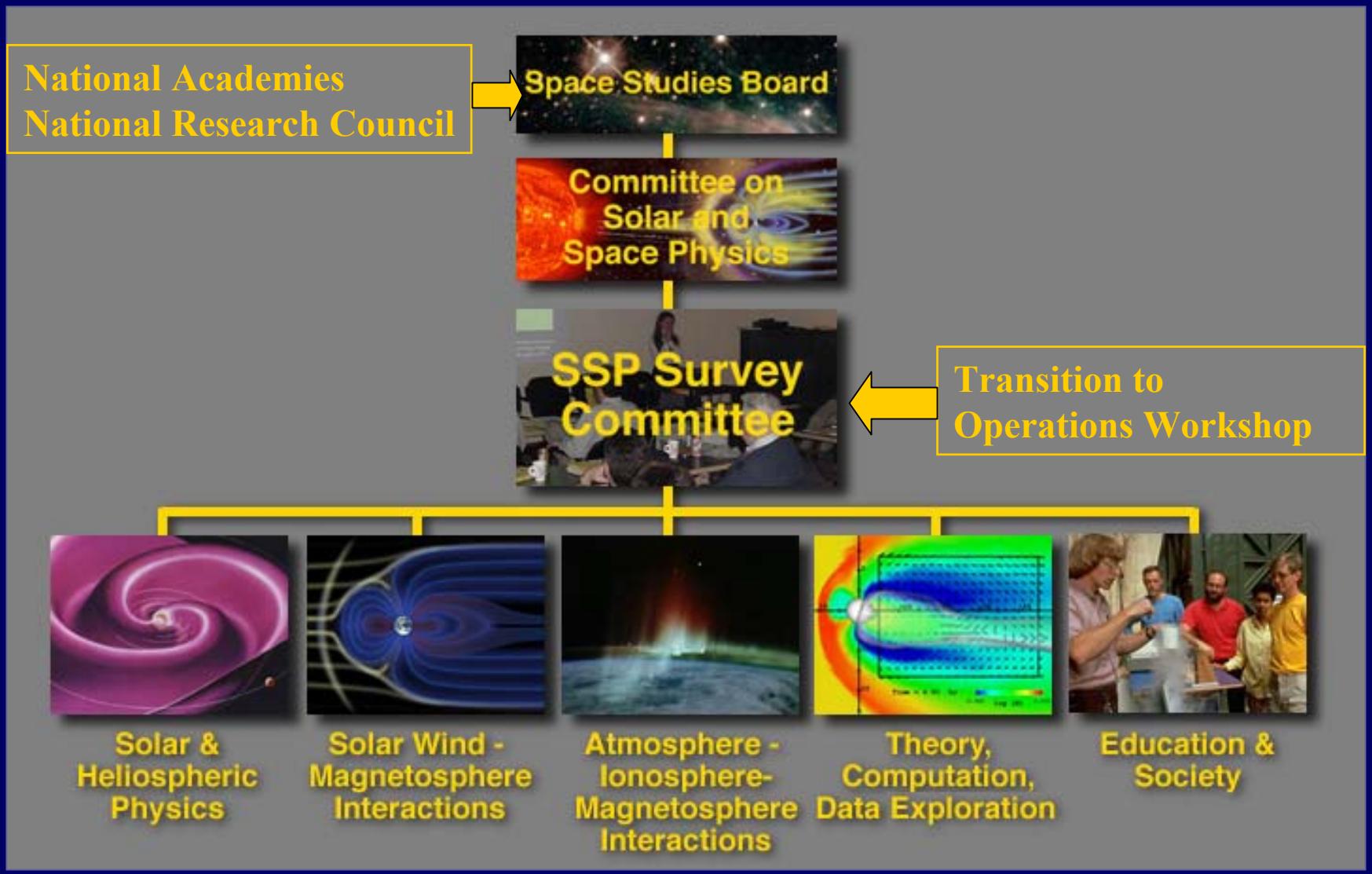
- Recommend **PRIORITIES** for the decade 2003-2013, including effective implementation of existing or planned programs.

- Recommend a **SYSTEMS APPROACH** to theoretical, ground-based, and space-based research that encompasses the flight programs and focused campaigns of **NASA**, the ground-based and basic research programs of **NSF**, and the complementary operational programs of other agencies such as **DoD, DoE, and NOAA**.

- Address the **HUMAN ASPECTS** of the field involving education, career opportunities, and public outreach.

- Suggest promising areas for the development of **NEW TECHNOLOGIES**.

Organization of the Study:



Funding for the study has been provided by the following sponsors:

National Aeronautics and Space Administration

National Oceanic and Atmospheric Administration

National Science Foundation

United States Air Force Office of Scientific Research

Office of Naval Research

Scientific Challenges:

- The Sun's Dynamic Interior and Corona
- The Heliosphere and Its Components
- The Space Environments of the Earth and Other Solar System Bodies
- Fundamental Space Plasma Physics/Astrophysical connections

Scientific Challenges:

- **The Sun's Dynamic Interior and Corona**
- **The Heliosphere and Its Components**
- **The Space Environments of the Earth and Other Solar System Bodies**
- **Fundamental Space Plasma Physics/Astrophysical connections**
- **Space Weather:** Developing near real-time predictive capability for understanding and quantifying the impact on human activities of dynamical processes at the Sun, in the interplanetary medium, and in the Earth's magnetosphere

Outline of the Report:

Chapter 1: Scientific Milestones and Challenges

Chapter 2: Integrated Research Strategy for Solar and Space Physics

Chapter 3: Technology Challenges

Chapter 4: Connections between Solar and Space Physics and Other Disciplines

Chapter 5: Solar and Space Environment Effects on Technology and Society

Chapter 6: Education and Public Outreach

Chapter 7: Strengthening the Solar and Space Physics Research Enterprise

Prioritization Criteria:

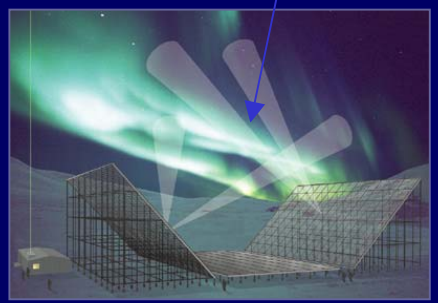
- **Scientific Merit**
  Importance of scientific problems to be addressed: major frontier or incremental? Impact on other disciplines
- **Contribution to National Goals**
  Impact on space weather prediction and protection; education; commerce and industry; public awareness; national image
- **Programmatic Aspects**
  Technological readiness (amount of technological development required prior to possible implementation; risk assessments)
  Adequate theoretical foundation (is enough known to formulate the questions whose answers would definitively solve the problem?)
  Timing (e.g., with respect to synergistic or precursor programs)
  Total run-out costs

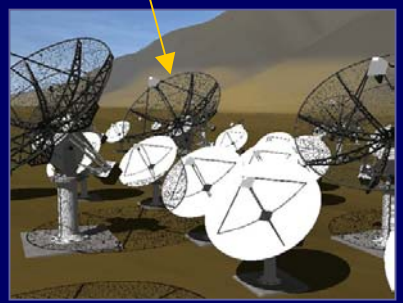
Program Categories:

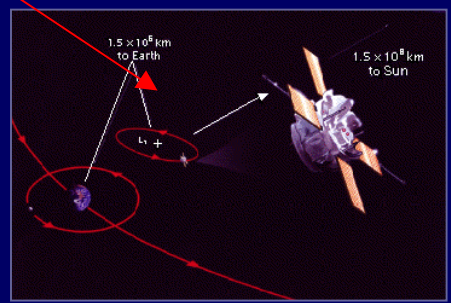
Large: > $400M
Moderate: $250M - $400M
Small: < $250M
Vitality: Essential research infrastructure matters

Small Programs:

Rank	Program	Description
1	**Frequency Agile Solar Radio Telescope**	Wide frequency-range (0.3 – 30 Ghz) radio telescope for imaging of solar features from a few hundred km above the visible surface to high in the corona.
2	**Advanced Modular Incoherent Scatter Radar**	Movable incoherent scatter radar with supporting optical and other ground-based instruments for continuous measurements of magnetosphere-ionosphere interactions.
3	**L1 Monitor**	Continuation of solar-wind and interplanetary magnetic field monitoring for support of Earth-orbiting space physics missions. Recommended for implementation by NOAA.
4	**Solar Orbiter**	U.S. instrument contributions to ESA spacecraft that periodically co-rotates with the Sun at 45 solar radii to investigate the magnetic structure and evolution of the solar corona.
5	**Small Instrument Distributed Ground Network**	NSF program to provide global-scale ionospheric and upper atmospheric measurements for input to global physics-based models.
6	**UNEX**	Revitalization of university-class Explorer program for more frequent access to space for focused research projects.



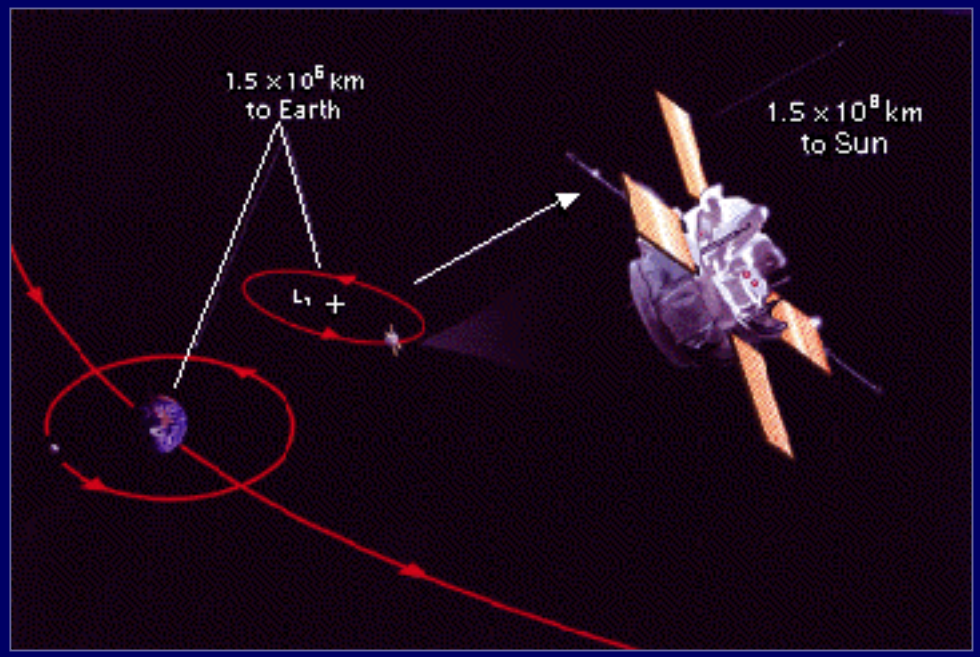




Cost Estimates/Technical Concerns:

Program	Cost (FY 2002 $M)	Technical Concern
Solar Probe	650	Moderate to High
GEC	300	Low
Geospace Network	400	Low
Jupiter Polar Mission	350	Moderate
Magnetospheric Multiscale	350	Low
Magnetospheric Constellation	325	High
Multi-Heliospheric Probes	300	Moderate
Solar Wind Sentinels	300	Moderate
Stereo Magnetospheric Imager	300	Low
Suborbital Program	30/yr (2002) - 60/yr (2012)	Low
Frequency Agile Solar Radio Telescope	60	Low
L1 Monitor	100	Low
Advanced Modular ISR	65	Low
Small Instrument Distributed Ground Network	5/yr	Low
Solar Orbiter	100	Moderate
UNEX	35/yr	Moderate

L1 Monitor

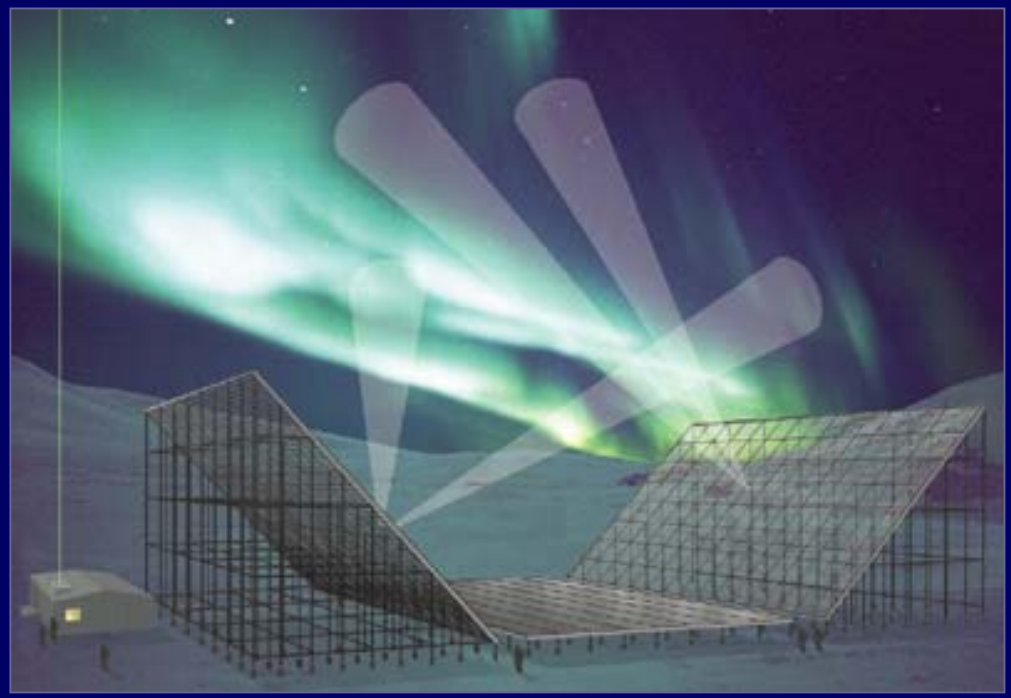


A spacecraft deployed at the Lagrangian (L1) point, 1.5 million kilometers upstream of Earth, to provide information about the state of the solar wind vital for both scientific studies and space weather applications.

Objectives:

- Measure solar wind velocity, density, ion and electron temperature, proton/alpha ratio, and magnetic field strength and orientation
- Provide real-time solar wind data for space weather applications

Advanced Modular Incoherent Scatter Radar

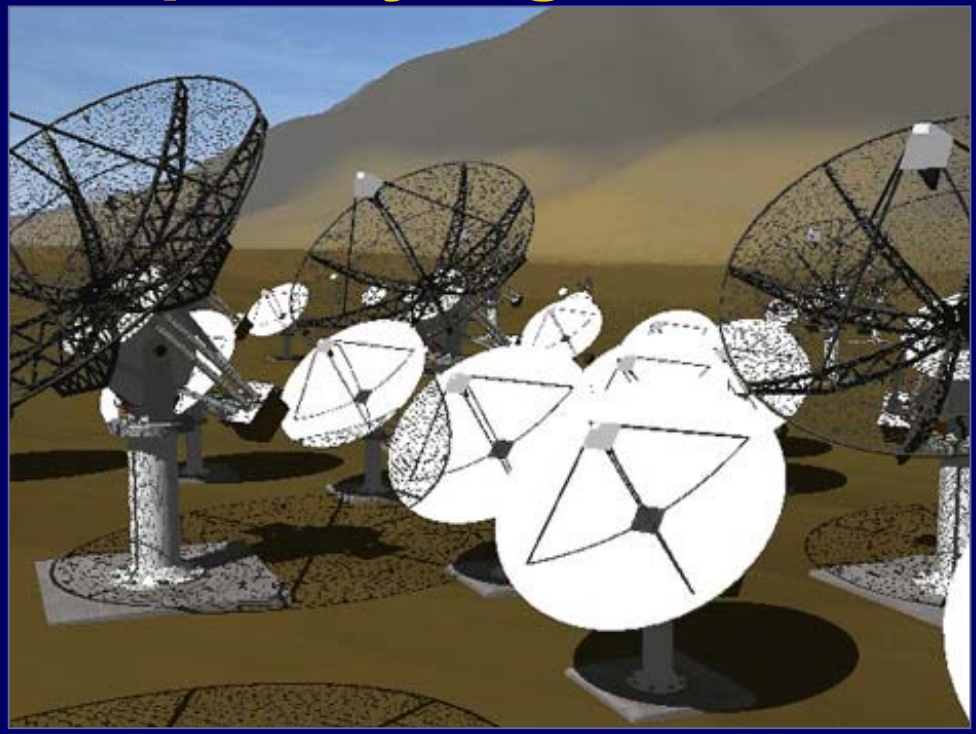


A state-of-the-art incoherent scatter radar, ringed with complementary optical and radio-wave-based systems and deployable in different geographic locations.

Objectives:

- Understand the coupling between the high-latitude neutral upper atmosphere and the high-speed, current-carrying plasma in the auroral oval
- Investigate deep polar cap ionosphere-thermosphere processes never before studied using the ISR technique
- Provide detailed ground-based observations in support of a wide range of spaceflight, data assimilation, and theory/modeling projects.

Frequency-Agile Solar Radio Telescope



A multi-frequency (~0.3 - 30 GHz) imaging array composed of as many as ~100 antennas for imaging the Sun with high spectral, spatial, and temporal resolution.

Objectives:

- Determine the spatial, temporal, and spectral characteristics of the site of energy release over a broad range of coronal heights
- Measure the magnetic field strength at coronal heights in flares and active regions
- Determine possible causes of coronal heating (nanoflares? current destabilization?)
- Detect coronal mass ejections, both off the limb and on the solar disk
- Characterize the 3-D thermal structure of the solar atmosphere

How Programs Map to Challenges:

	SCIENTIFIC CHALLENGES				
MISSIONS AND FACILITIES	***The Dynamic Solar Interior and Corona***	***The Heliosphere and Its Components***	***Earth and Planetary Space Environments***	***Fundamental Space Plasma Physics***	***Space Weather***
Frequency Agile Solar Radio Telescope	■			■	■
Advanced Modular Incoherent Scatter Radar			■		■
L1 Monitor					■
Solar Orbiter	■	■			
Small Instr. Distributed Ground-based Network			■		■
University Explorers	■		■	■	■
Solar Dynamics* Observatory	■			■	■
Advanced* Technology Solar Telescope	■			■	■

*planned or approved initiatives

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Frequency Agile Solar Radio Telescope	■			■	■
Advanced Modular Incoherent Scatter Radar			■		■
L1 Monitor					Essential
Solar Orbiter	■	■			
Small Instr. Distributed Ground-based Network			■		■
University Explorers	■		■	■	■
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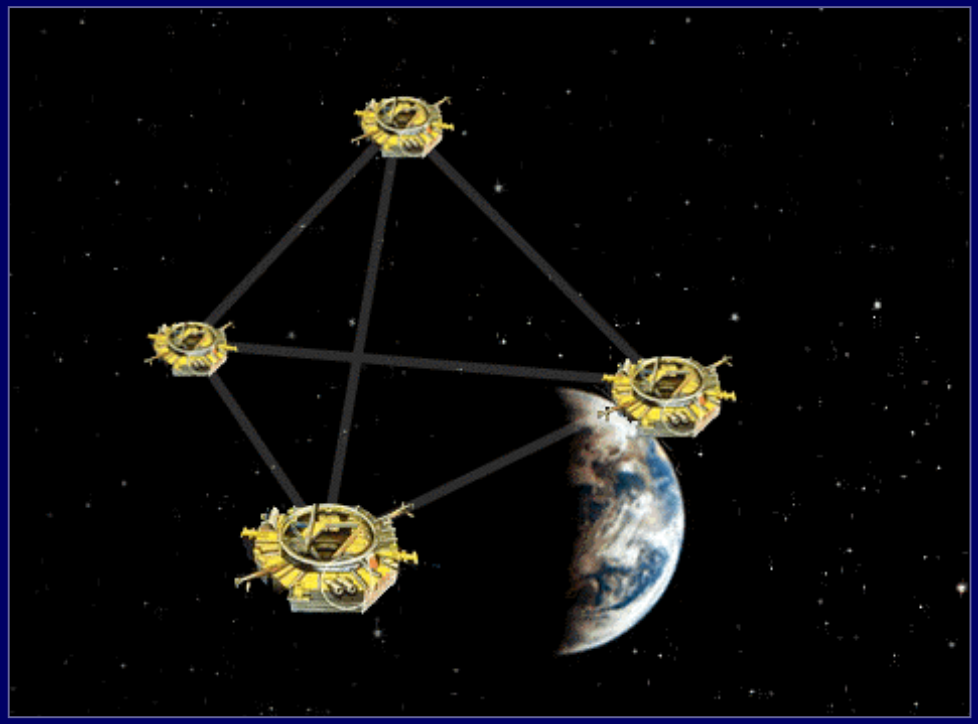
Magnetospheric Multiscale (MMS)

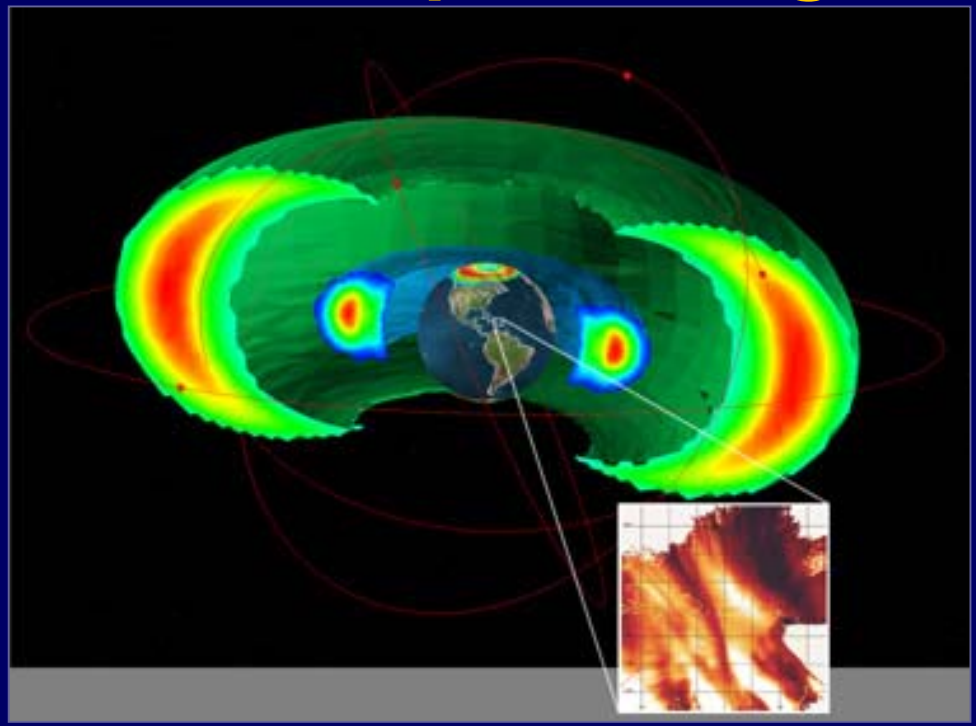


The 4 MMS spacecraft will study the fundamental physical processes that transport, accelerate, and energize plasma in the boundary layers of Earth's magnetosphere.

Objectives:

- Determine where and under what conditions magnetic reconnection occurs at the magnetopause and in the magnetotail
- Determine the mechanisms for the acceleration of charged particles in the plasma boundary layers
- Determine the cause and structure of plasma injection in the near-Earth tail
- Determine physical processes responsible for turbulence in the magnetosheath, magnetopause, and plasma sheet

LWS Geospace Program



Two radiation belt probes and two ionosphere-thermosphere probes will study the effects of space storms on regions of geospace that profoundly influence the operation of critical technological systems.

Objectives:

- Characterize and understand the acceleration, global distribution, and variability of radiation belt electrons and ions that produce the harsh space environment for spacecraft and humans
- Characterize and understand mid-latitude ionospheric variability and the irregularities that affect communications, navigation, and radar systems

Vitality Programs:

Rank	Program	Description
1	**NASA SR&T**	NASA research and analysis program.
2	**National Space Weather Program**	Multi-agency program led by the NSF to support focused activities to improve scientific understanding of geospace in order to provide better specifications and predictions.
3	**Coupling Complexity**	NASA/NSF Theory and modeling program to address multi-process coupling, nonlinearity, and multi-scale and multi-regional feedback.
4	**Solar and Space Physics Information System**	Multi-agency program for integration of multiple data sets and models in a system accessible by the entire solar and space physics community.
5	**Guest Investigator Program**	NASA program for broadening the participation of solar and space physicists in space missions.
6	**Sun-Earth Connection Theory and LWS Data Analysis, Theory, and Modeling Programs**	NASA program to provide long-term support to critical-mass groups involved in specific areas of basic and targeted basic research.
7	**Virtual Sun**	Multi-agency program to provide a systems-oriented approach to theory, modeling, and simulation that will ultimately provide continuous models from the solar interior to the outer heliosphere.

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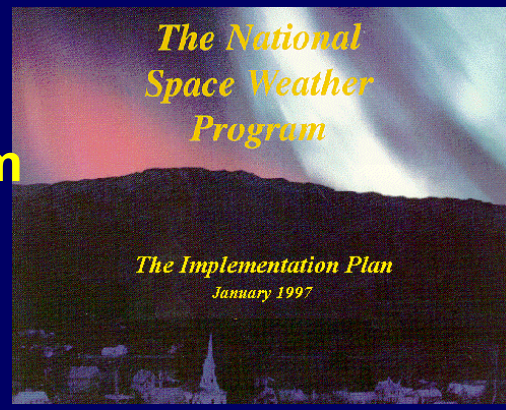
The National Space Weather Program

Challenge 1: **Developing processes and policies for the monitoring of the space weather environment**

Chapter 5: Solar and Space Environment Effects on Technology and Society

The National Space Weather Program



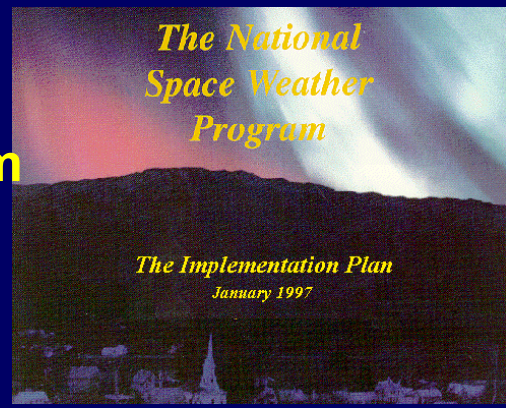
Challenge 1: **Developing processes and policies for the monitoring of the space weather environment**

Findings:

- **The U.S. federal agencies that have important research and/or mission interests in the solar-terrestrial environment are taking strong initiatives to establish, nurture, and evolve an effective national program in space weather.**

Chapter 5: Solar and Space Environment Effects on Technology and Society

The National Space Weather Program



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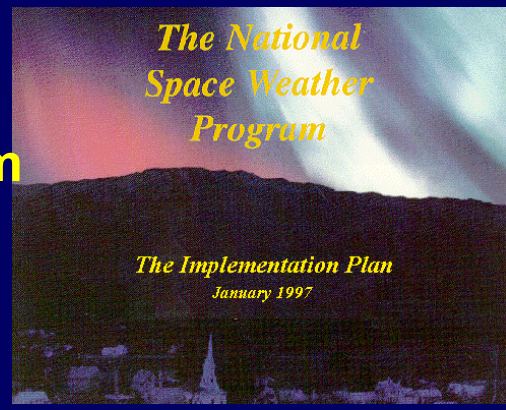
Chapter 5: Solar and Space Environment Effects on Technology and Society

The National Space Weather Program



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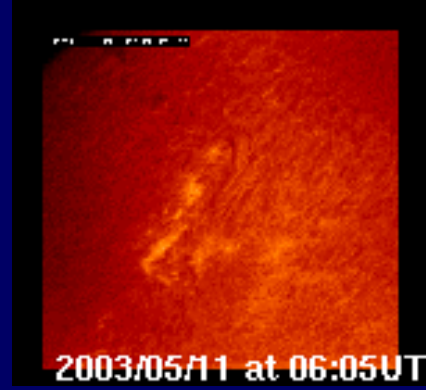
- **There is growing interest in the private sector for the providing of space weather products to both the private and the public sectors.**
- **As a result of all of these activities, there are numerous research and policy issues that face the national efforts in space weather and that demand that new attention be given by all interested parties.**

Effects on Technology and Society:



Monitoring the Solar-Terrestrial Environment

Challenge 2: Determining those research instruments and observations that are required to provide the basic modeling interactions of the solar-terrestrial environment with technical systems and for making sound technical decisions

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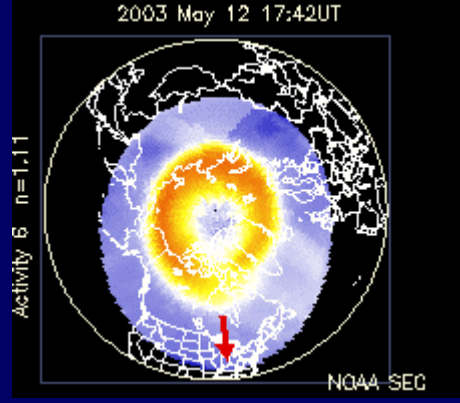

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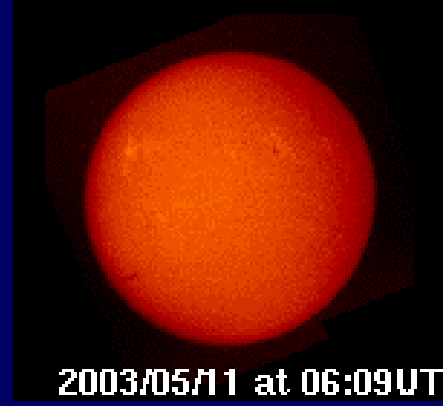
Effects on Technology and Society:



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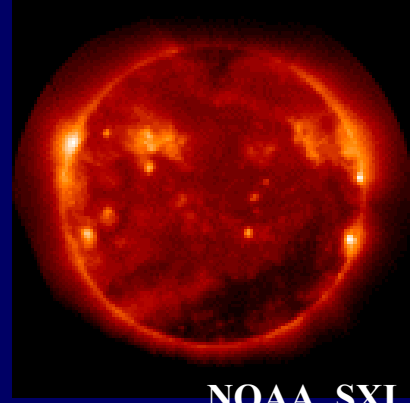
NOAA SXI

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Recommendation: NASA and NOAA should initiate the necessary planning to transition solar and geospace imaging instrumentation into operational programs for the public and private sectors.

Effects on Technology and Society:

Transition from Research to Operations

Challenge 3: Establishing, maintaining , and evolving mechanisms for the efficient transfer of new models of the solar-terrestrial environment into the user community

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Recommendation: The relevant federal agencies should establish an overall verification and validation program for all publicly funded models and system-impact products before they become operational.

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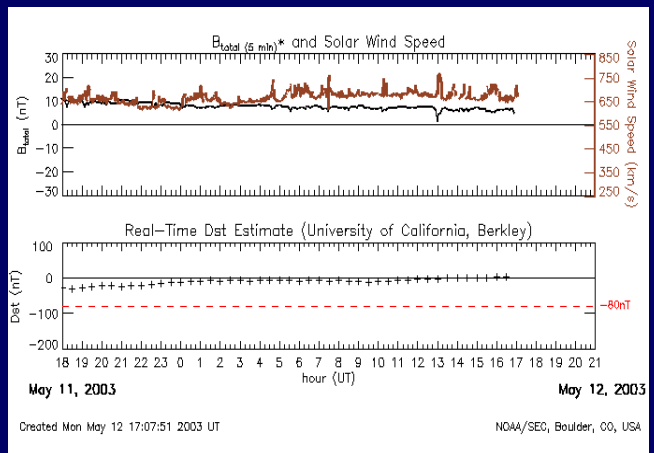
Recommendation: The operational federal agencies, NOAA and DOD, should establish procedures to identify and prioritize operational needs, and these needs should determine which model types are selected for transitioning via the Community Coordinated Modeling Center and Rapid Prototyping Centers. After the needs have been prioritized, procedures should be established to determine which of the competing models, public or private, is best suited for a particular operational requirement.

Bz, measured and predicted

Prob. Dst < -80 nT



NOAA Chen Model 11 May 2003

Effects on Technology and Society:

Data Acquisition and Availability

***Challenge 4*: Assessing the capability for predicting the solar-terrestrial impact on specific technological systems as well as for predicting space weather in general and improving this capability as needed.**

Recommendation: The **DOD and NOAA** should be the lead agencies in the acquisition of all data sets required for accurate specification and forecast modeling, including data from the international community.
Because it is extremely important to have real-time data, both space- and ground-based, for predictive purposes, **NOAA and DOD** should invest in new ways to acquire real-time data from all those ground- and space-based sources available to them. All data acquired should contain error estimates, which are required by data assimilation models.

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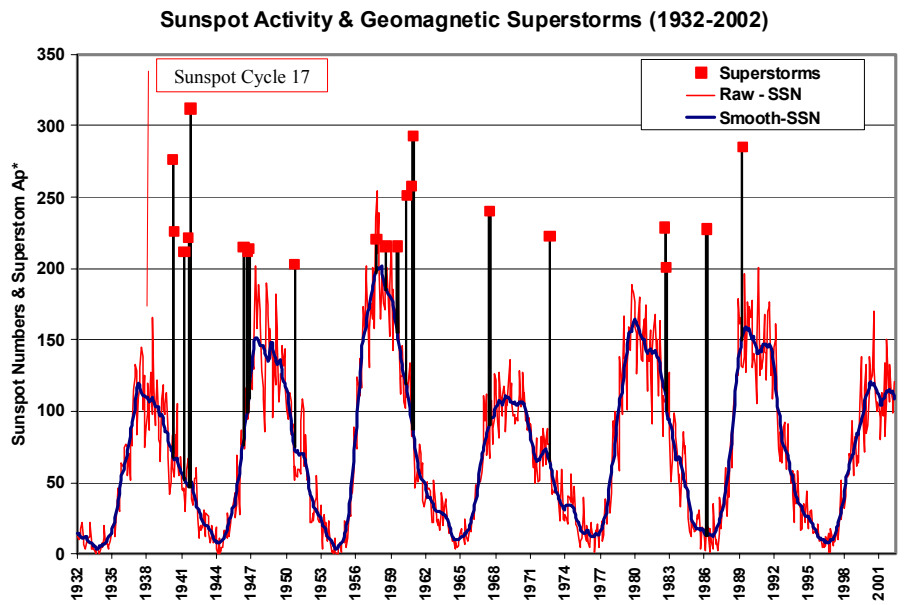
Recommendation: A new centralized database of extreme space weather conditions should be created that covers as many of the relevant space weather parameters as possible.



Geomagnetic superstorms
Metatech Corp.

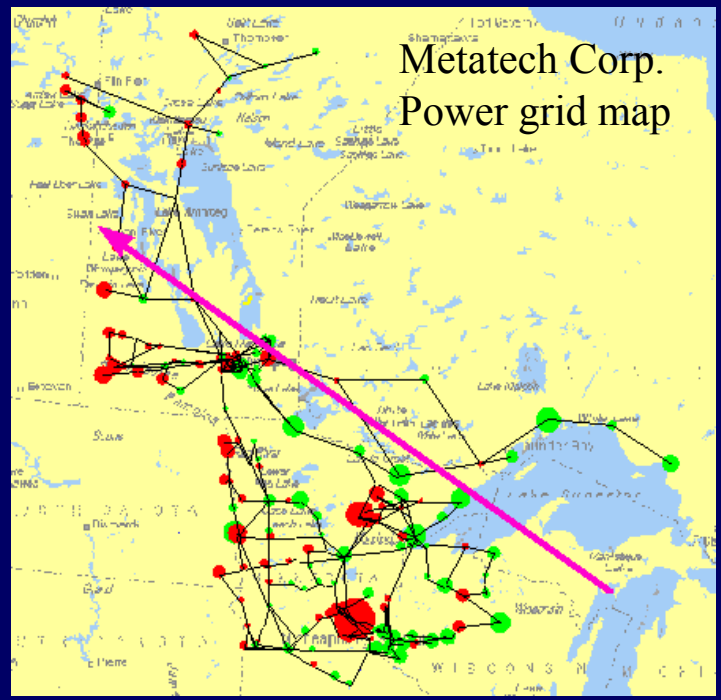
Public and Private Sectors in Space Weather Applications

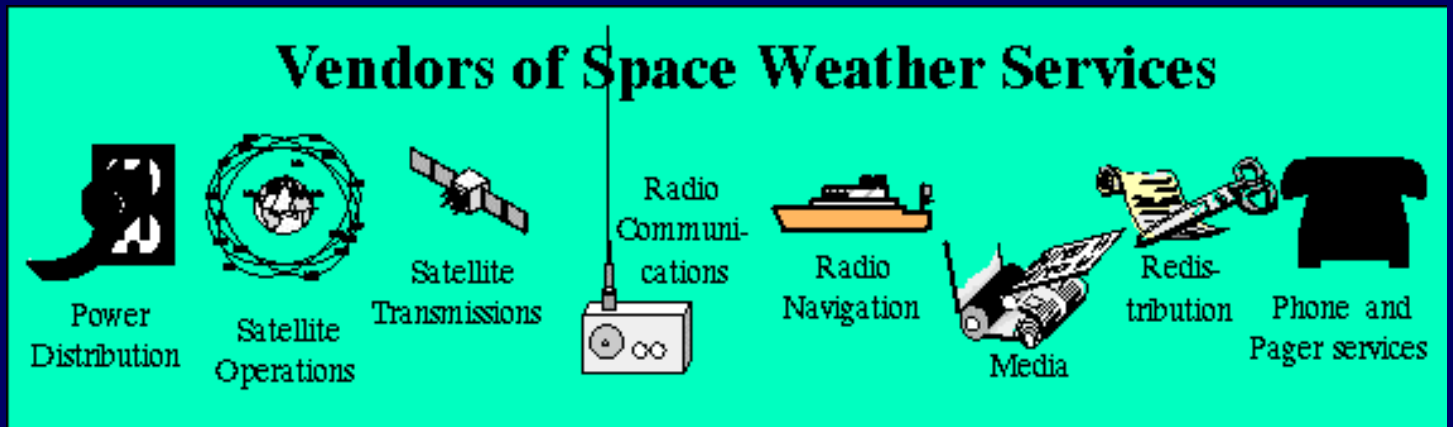
Challenge 5: Determining the appropriate roles for the public and the private sectors in acquiring, assessing, and disseminating information and models related to the solar-terrestrial environment in the context of its relevance for technological systems.

Public and Private Sectors in Space Weather Applications

Challenge 5: Determining the appropriate roles for the public and the private sectors in acquiring, assessing, and disseminating information and models related to the solar-terrestrial environment in the context of its relevance for technological systems.

Clear policies describing government and industry roles, rights, and responsibilities should be developed and published by all agencies and interested commercial enterprises involved in space weather activities in order to optimize the benefits of the national investments, public and private, that are being made.





NOAA Web site

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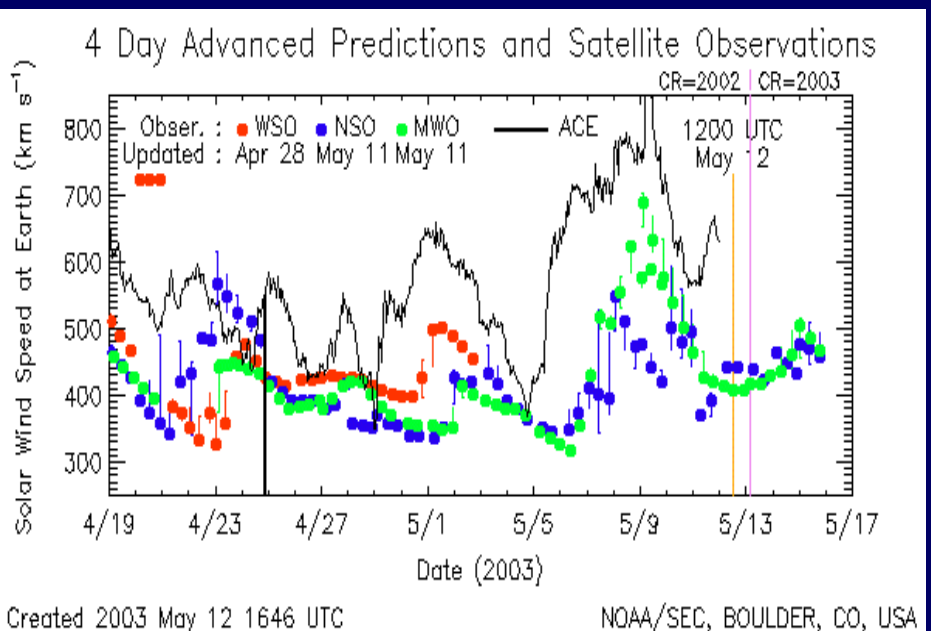
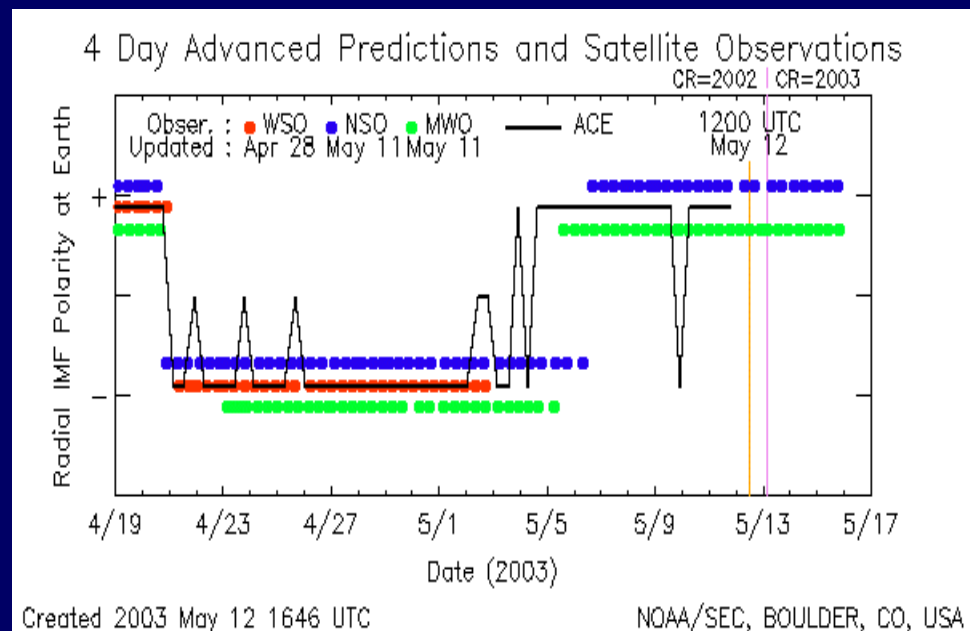
Technology Challenges:

Modeling the Space Environment

Recommendation: Existing **NOAA and DOD** facilities should be expanded to accommodate the large-scale integration of space- and ground-based data sets into physics-based models of the geospace environment.





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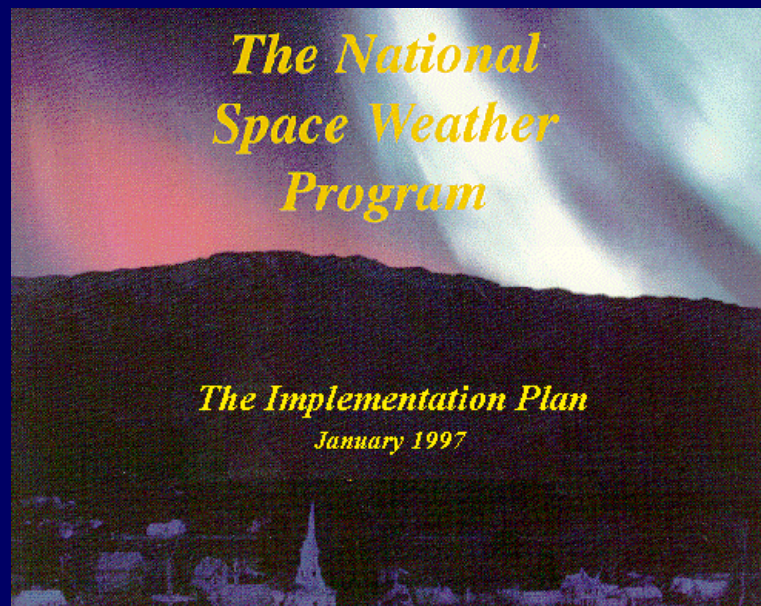
Strengthening the SSP Research Enterprise:

Interagency Cooperation and Coordination

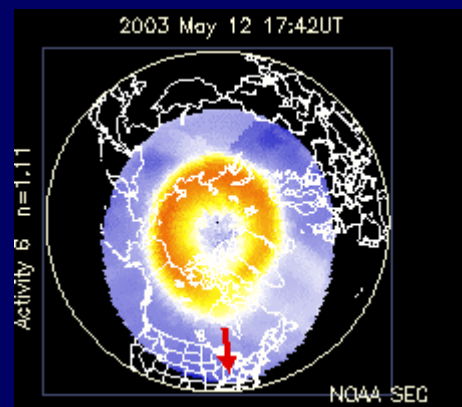
Recommendation: The principal agencies involved in solar and space physics research - **NASA, NSF, NOAA, and DoD** - should devise and implement a management process that will ensure a high level of coordination in this research field, and that will disseminate the results of such a coordinated effort - including data, research opportunities, and related matters - widely and frequently to the research community.

Recommendation: For space-weather-related applications, increased attention should be devoted to coordination among **NASA, NOAA, NSF, and DoD** of research findings, models, and instrumentation so that new developments in each of these areas can quickly be incorporated into operational and applications programs of **NOAA and DoD**.



The Sun to the Earth – and Beyond

An Integrated Strategy for Solar and Space Physics, 2003-2013



SUMMARY

The integrated strategy developed by the Decadal Survey presents a challenging research and operational program in solar and space physics, a program in which both the public and private sectors have major roles in advancing understanding and important applications of the field.

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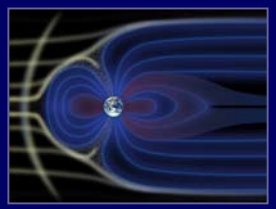

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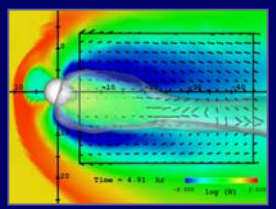

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Backup Slides

Large and Moderate Programs:

Type of Program	Rank	Program	Description
Large	**1**	**Solar Probe**	Spacecraft to study the heating and acceleration of the solar wind through in situ measurements and some remote-sensing observations during one or more passes through the innermost region of the heliosphere (from ~0.3 AU to as close as 3 solar radii above the Sun's surface).
Moderate	**1**	**Magnetospheric Multiscale**	Four-spacecraft cluster to investigate magnetic reconnection, particle acceleration, and turbulence in magnetospheric boundary regions.
	2	**Geospace Network**	Two radiation-belt mapping spacecraft and two ionospheric mapping spacecraft to determine the global response of geospace to solar storms.
	3	**Jupiter Polar Mission**	Polar-orbiting spacecraft to image the aurora, determine the electrodynamic properties of the Io flux tube, and identify magnetosphere-ionosphere coupling processes.
	4	**Multispacecraft Heliospheric Mission**	Four or more spacecraft with large separations in the ecliptic plane to determine the spatial structure and temporal evolution of CMEs and other solar-wind disturbances in the inner heliosphere.
	5	**Geospace Electrodynamic Connections**	Three to four spacecraft with propulsion for low-altitude excursions to investigate the coupling among the magnetosphere, the ionosphere, and the upper atmosphere.
	6	**Suborbital Program**	Sounding rockets, balloons, and aircraft to perform targeted studies of solar and space physics phenomena with advanced instrumentation.
	7	**Magnetospheric Constellation**	Fifty to a hundred nanosatellites to create dynamic images of magnetic fields and charged particles in the near magnetic tail of Earth.
	8	**Solar Wind Sentinels**	Three spacecraft with solar sails positioned at 0.98 AU to provide earlier warning than L1 monitors and to measure the spatial and temporal structure of CMEs, shocks, and solar-wind streams.
	9	**Stereo Magnetospheric Imager**	Two spacecraft providing stereo imaging of the plasmasphere, ring current, and radiation belts, along with multispectral imaging of the aurora.

Geospace Electrodynamic Connections

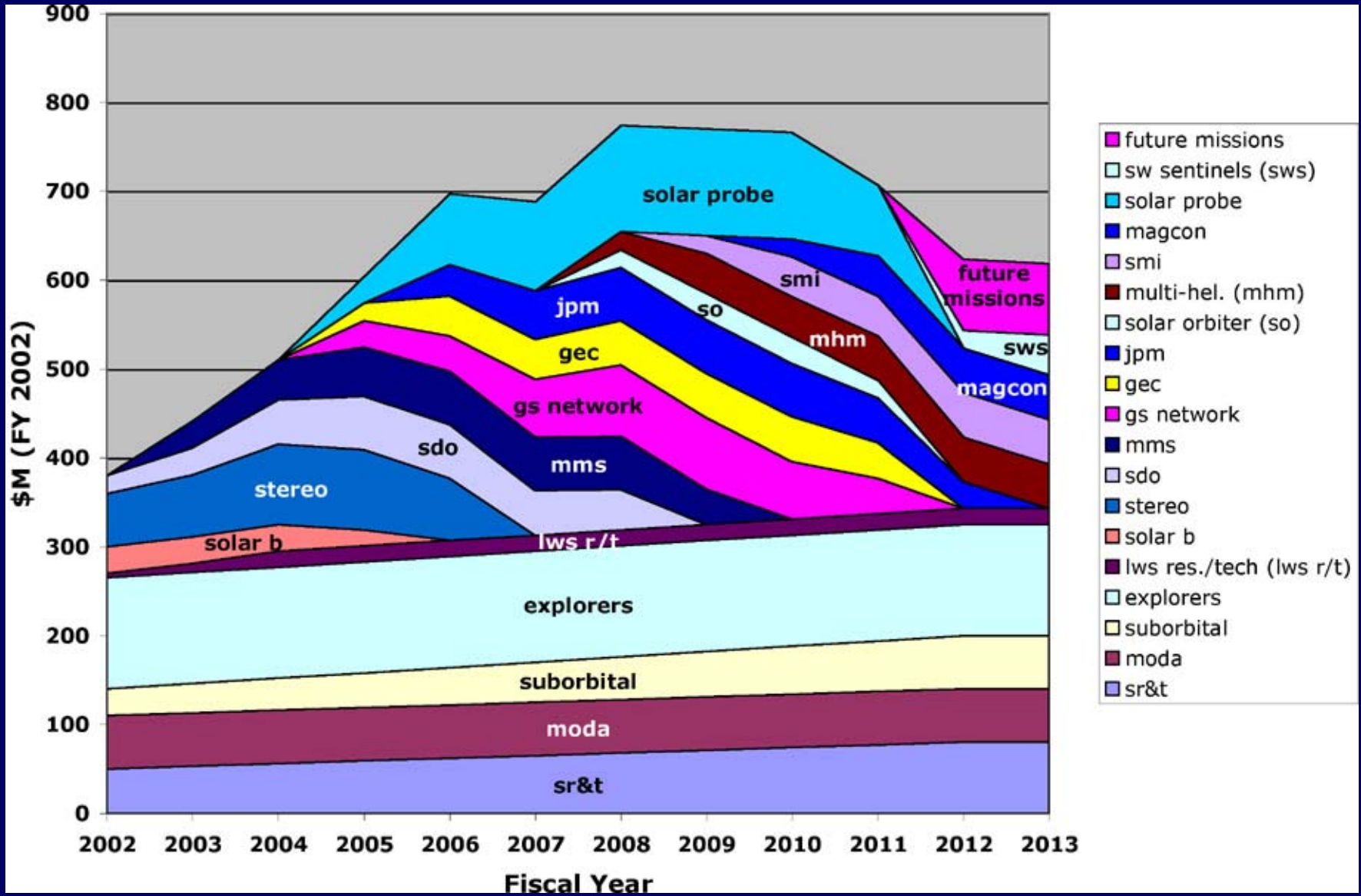
Multiple identically instrumented spacecraft in high inclination orbit performing dipping maneuvers to sample the region of the upper atmosphere where significant energy transfer between the magnetosphere, ionosphere, and thermosphere occurs.

Objectives:

- Discover the spatial and temporal scales on which magnetospheric energy input into the upper atmosphere occurs
- Determine the spatial and temporal scales on which the atmosphere responds to this input
- Quantify the altitude dependence of the response
- Determine the upper atmosphere's role in modulating the energy exchange with the magnetosphere

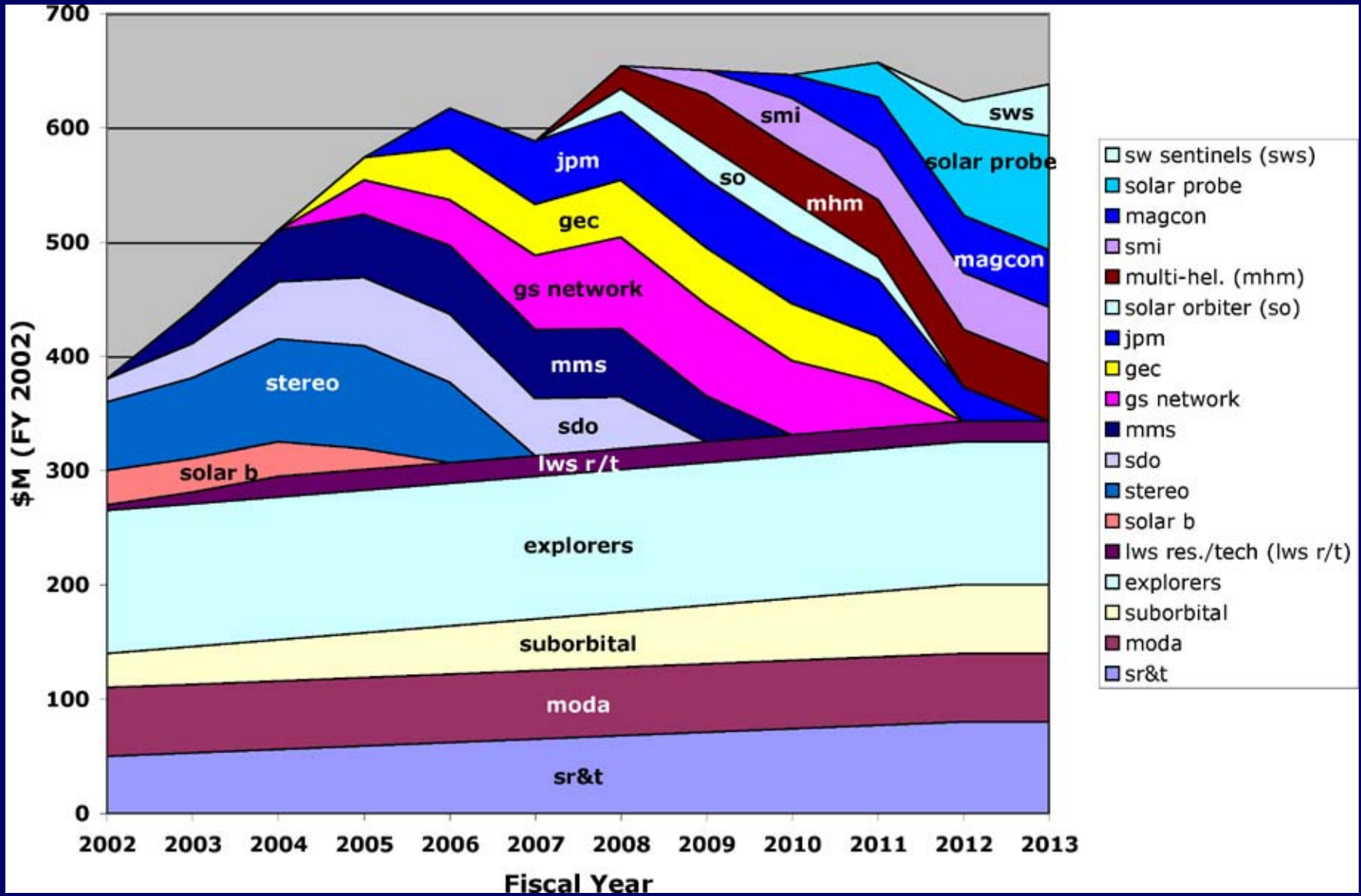
NASA Mission Costs 1:

(Solar Probe Starts in '03)

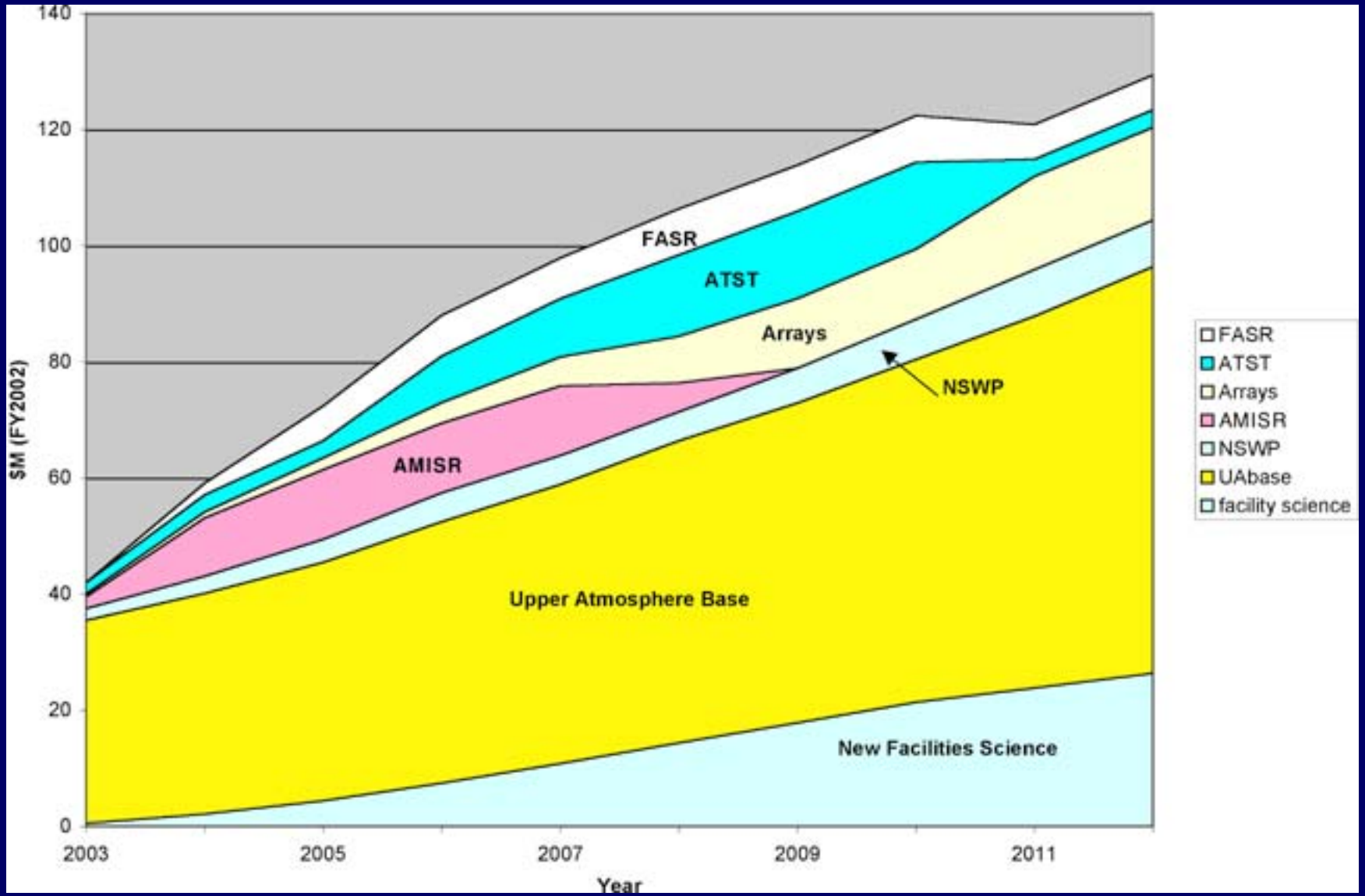


NASA Mission Costs 2:

(Solar Probe Starts in '09)



NSF Program Costs:



How Programs Map to Challenges:

	SCIENTIFIC CHALLENGES				
MISSIONS AND FACILITIES	***The Dynamic Solar Interior and Corona***	***The Heliosphere and Its Components***	***Earth and Planetary Space Environments***	***Fundamental Space Plasma Physics***	***Space Weather***
Solar Probe	■	■		■	
GEC			■	■	■
Geospace Network			■		■
Jupiter Polar Mission			■	■	
MMS			■	■	
Magnetospheric Constellation			■	■	■
Multi-spacecraft Heliospheric Mission		■		■	
Solar Wind Sentinels		■			■
Stereo Magnetospheric Imager			■		■
Suborbital Program	■		■	■	